Journal of Fish Biology (1999) **55**, 876–879
Article No. jfbi.1999.1031, available online at http://www.idealibrary.com on IDEAL®

BRIEF COMMUNICATIONS

Seasonal differences in routine oxygen consumption rates of the bonnethead shark

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(*Received 23 March 1999, Accepted 9 June 1999*)

Routine oxygen consumption rates of bonnethead sharks, *Sphyrna tiburo*, increased from $141{\cdot}3 \pm 29{\cdot}7$ mg O_2 kg^{-1} h^{-1} during autumn to $218{\cdot}6 \pm 64{\cdot}2$ mg O_2 kg^{-1} h^{-1} during spring, and $329{\cdot}7 \pm 38{\cdot}3$ mg O_2 kg^{-1} h^{-1} during summer. The rate of routine oxygen consumption increased over the entire seasonal temperature range (20–30° C) at a $Q_{10}=2{\cdot}34$.

Key words: shark; oxygen consumption; temperature; Q_{10}.

Seasonal change in temperature is a key environmental variable and, in ectothermic vertebrates, plays a major role in controlling physiological function, such as oxygen consumption rate (Schmidt-Neilsen, 1983). The effect of temperature on oxygen consumption in teleosts has been studied, examining both acute (Burggren & Roberts, 1991) and seasonally acclimatized organisms (reviews in Johnston & Dunn, 1987; Jensen *et al.*, 1994). However, temperature effects on the oxygen consumption of elasmobranchs have been investigated only among skate and ray species (Du Preez *et al.*, 1988; Hopkins & Cech, 1994). There are currently no studies on the seasonal changes in oxygen consumption rate in a shark species.

The bonnethead shark *Sphyrna tiburo* (L.), is a common inhabitant of shallow coastal areas throughout the Gulf of Mexico and south-eastern United States. During cooler months when many species of sharks migrate to warmer areas, bonnethead sharks may remain active in shallow cooler waters moving from shallow bays and estuaries in summer to shallow oceanic environments in winter (Hueter & Manire, 1994; J. K. Carlson, pers. obs.). Moreover, bonnethead sharks are captured in gillnets at temperatures from 15 to 34° C (Hueter & Manire, 1994; Carlson, unpublished data) suggesting this species is eurythermal. Thus, bonnethead sharks inhabiting different seasonal thermal environments may have radically different oxygen consumption rates which in turn could affect construction of energy budgets, and overall bioenergetic analysis.

Sharks (mean $=1{\cdot}1 \pm 0{\cdot}06$ kg) were captured from April to November. The procedures of capture, transporting, and holding are given in Parsons & Carlson (1998).

Routine oxygen consumption rate measurements were made in a closed, circular, respirometer (inner diameter 182 cm × depth 58 cm) constructed using a modified 1500-l polyethylene tank. The tank was permanently sealed using silicon sealant and a plywood and Plexiglas lid. Plexiglas windows cut into the sides and top of the respirometer allowed for observations during experiments. One window in the lid was removable which allowed for placement and removal of the shark.

The experiment began by filling the respirometer with filtered, UV-sterilized sea water pumped directly from an adjacent aquaculture facility at 29·8‰ ($\pm 0{\cdot}8$ S.D.) salinity and

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0022–1112/99/100876+04 $30.00/0

dissolved oxygen of 6·1 mg l^{-1} ($\pm$ 0·5 S.D.). The respirometer was overfilled to reduce the number of airpockets and any remaining were forced to the opening using a squeege. A shark was placed in the respirometer through the removable window and, following Parsons (1990), allowed to acclimate for 24 h. A Microelectrodes polarographic oxygen electrode (Model MI-730) connected to a Microelectrodes amplifier (Model OM-3) and Linseis strip chart recorder (Model L-4000) was calibrated at each experimental temperature and pressure prior to insertion into the respirometer. Preceding and immediately after each experiment, oxygen concentration was verified using a YSI Model 51B or YSI Model 55 oxygen meter. During the experiment, sharks swam continuously around the outer edge of the respirometer which allowed for water mixing. No significant background respiration was measured when the experiment was conducted minus the shark.

Oxygen consumption rate (per unit body mass) was determined using the general equation;

$$V_{O_2} = b\ a\ v\ w^{-1}$$

where V_{O_2} is oxygen consumption in mg O_2 kg^{-1} h^{-1}, b is the rate of change of oxygen in the respirometer, a is the solubility of oxygen calculated at the experimental temperature and pressure, v is the volume of the respirometer and w is the wet weight of the shark.

Swimming speed (cm s^{-1}) was measured every 30 min by noting the time required for the shark to pass between two points of a known distance marked on the respirometer. When dissolved oxygen concentrations reached 5·0 mg l^{-1}, the seal was broken on the tank, the shark was removed from the respirometer, weighed (kg $\pm$ 0·01 kg), measured ($\pm$ 1·0 cm), and returned to the holding area. The duration of all experiments ranged from 1·2 to 3·6 h. Because bonnethead sharks exhibit changes in diurnal activity patterns, possibly due to changes in light intensity (Parsons & Killam, 1991), experiments were conducted under constant light to eliminate the influence of environmental photoperiod.

Overall routine oxygen consumption was calculated for individual sharks at each temperature as the grand mean of all oxygen consumption rates measured regardless of swimming speed. Q_{10}, a measure of the rate of change within 10° C, was calculated using methods outlined in Schmidt-Neilsen (1983).

Sharks swam at steady speeds throughout all experiments and exhibited similar oxygen consumption rates throughout all times of the day. Average swimming speed for all sharks at each season was 24·7 $\pm$ 0·3 cm s^{-1} during fall (October–November, mean temperature = 20·0 $\pm$ 1·6° C, n=7), 27·3 $\pm$ 1·4 cm s^{-1} during spring (April–May, mean temperature = 25·3 $\pm$ 1·0° C, n=7), and 27·0 $\pm$ 0·7 cm s^{-1} during summer (July–August, mean temperature = 29·6 $\pm$ 0·8° C, n=12). No significant difference was found between swimming speed and season ($P \geq 0{\cdot}05$).

Routine oxygen consumption rates increased with increasing seasonal temperature. Oxygen consumption rate for all sharks was 141·3 $\pm$ 29·7 mg O_2 kg^{-1} h^{-1} during autumn, 218·6 $\pm$ 64·2 mg O_2 kg^{-1} h^{-1} during spring, and 329·7 $\pm$ 38·3 mg O_2 kg^{-1} h^{-1} during summer (Fig. 1). Log transformed routine oxygen consumption rates were significantly different (one-factor ANOVA; $P<0{\cdot}01$) among seasons. Tukey *post hoc* comparison found significant differences only between autumn and summer ($P<0{\cdot}05$).

The Q_{10} analysis found oxygen consumption rate sensitivity was similar throughout the seasonal temperature range. The rate of change between 20 and 25° C increased at a Q_{10}=2·39; and between 25 and 30° C the Q_{10}=2·29. The rate of routine oxygen consumption increased over the entire seasonal temperature range (20–30° C) at a Q_{10}=2·34.

Few studies have examined elasmobranch oxygen consumption at more than one temperature but results so far have shown a variety of interspecific variation. Du Preez *et al.* (1988) determined an overall Q_{10} response of 1·87 between 10 and 25° C for bullray, *Myliobatis aguila* (L.), but for guitarfish, *Rhinobatus annulatus* Müller & Henle, the Q_{10} was 2·27 between 15 and 25° C. Hopkins & Cech (1994) reported an overall Q_{10} of 3·0 for

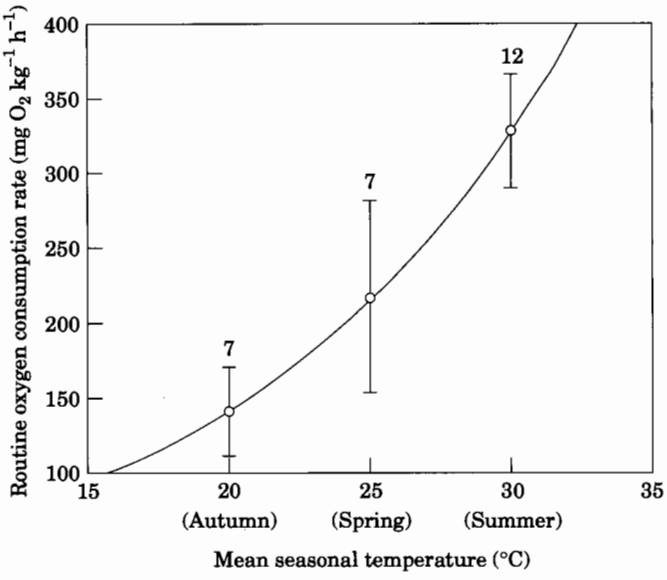

FIG. 1. Mean routine oxygen consumption rate (± S.E.) of bonnethead sharks at three seasons. Mean temperatures at each season were 20·0 ± 1·6° C during fall (October–November), 25·3 ± 1·0° C during spring (April–May) and 29·6 ± 0·8° C during summer (July–August). The number above each mean is the sample size.

bat rays, *Myliobatis californica* Gill. Although it is likely that interspecific variation occurs in Q_{10}, the increase in length of acclimation at each experimental temperature may result in a lower sensitivity in oxygen consumption rate (Burggren & Roberts, 1991). For example, the higher Q_{10} determined for bat rays may likely be a result of the response of oxygen consumption rate to acute changes in temperature rather than a higher sensitivity to temperature changes (Hopkins & Cech, 1994).

Rates of oxygen consumption for bonnethead sharks were similar to those reported from other studies. Parsons (1990) determined an oxygen consumption rate of 246 mg O_2 kg^{-1} h^{-1} for 1·0-kg bonnethead sharks at 25° C. Parsons & Carlson (1998) reported oxygen consumption rates of 115 mg O_2 kg^{-1} h^{-1} for bonnethead sharks (mean weight = 1·6 kg) at 19° C under normoxic conditions.

The shallow coastal estuarine and marine habitats inhabited by bonnethead sharks are exposed to large fluctuations in temperature from summer to winter months. Most coastal species of sharks are captured in more narrow temperature regimes (Carlson, unpublished data). Because of the wide temperature range bonnethead sharks are exposed to and the resulting change in oxygen consumption rates found in this study, bonnethead sharks are likely to have widely varying rates in bioenergetics, food consumption, and energy budgets. Future studies should investigate this possibility.

The National Marine Fisheries Service, Panama City Laboratory and the University of Mississippi provided financial support. Reference to trade names does not imply endorsement by the National Marine Fisheries Service. R. Holberton, C. Manire, and an anonymous reviewer provided suggestions on earlier versions of this manuscript. All experiments were conducted under and approved by the Institutional Animal care and Use Committee of the University of Mississippi.

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